

The Antarctic Ice Borehole Probe

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Abstract The Antarctic Ice Borehole Probe mission is a glaciological investigation, scheduled for November 2000-January 2001, that will place a probe in a hot-water drilled hole in the West Antarctic ice sheet. The objectives of the probe are to observe ice-bed interactions with a downward looking camera, and ice inclusions and structure, including hypothesized ice accretion, with a side-looking camera. The Probe mission also serves as a stepping-stone in the development of technology to acquire data in extreme ice and liquid environments. The information and experience will aid projects involving exploration in ice/liquid environments, including missions to Lake Vostok in Antarctica, Mars Polar Caps and Europa, Jupiter's moon. This focus of this paper is to describe the design and use of the probe.

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1. INTRODUCTION

The Antarctic Ice Borehole Camera mission is a glaciological study to be conducted in the 2000-2001 Antarctic field season (November 2000-January of 2001), in collaboration with ice stream basal process studies conducted by scientists from the California Institute of Technology. The system designed and built for the mission is simply called the Probe hereafter; its design and implementation was funded by NASA Earth Sciences Enterprise, and its deployment was funded by the Office of Polar Program of the National Foundation. The mission study has scientific objectives of obtaining data on ice stream-bed interactions, on the mineralogical material in the basal ice, and on ice structure in the lower ice sheet, with emphasis on observations of hypothesized accreted ice in areas of the ice streams known as sticky spots. These scientific objectives have resulted in observational objectives to acquire video images with a downward-looking camera and sequential digital still images with a

side-looking camera, with the attendant requirement to provide illumination for both geometries.

The development, test and deployment of a Probe needed to meet these requirements also serves to develop the technology for acquisition of optical data in remote, high pressure, liquid and ice environments. The experience and information will be of value in future terrestrial and planetary projects, including missions to sub-glacial lakes such as Lake Vostok in Antarctica, the Mars Polar Caps and to Europa, a Jovian moon thought to have a deep ocean beneath an ice crust.

The task of the Antarctic Ice Borehole Camera Mission is to develop an instrumented ice/water Probe to be deployed at depths up to 1.4 km in deep ice wells to obtain image data both down the hole and laterally into the ice. A key challenge for the Probe is in the extreme operating pressure, the consequence of being at a depth of 1.4 km of fresh water, in which the structure, equipment, and optical elements must function. While assembly is performed at room temperature, the environmental pressure of the Probe ranges to over 130 atm at depth in the ice well. The narrow diameter of the probe also creates challenges, requiring miniaturization of instruments and complex lighting geometry. In addition there was a time constraint, with quick feasibility testing set for early February, system testing for August, and the mission itself in November; and the budget for the development was quite modest.

Deep boreholes will be drilled through the Antarctic ice sheet using a proven hot-water jet technology developed by Caltech (1). The boreholes will be kept large enough (~17 cm diam.) by reaming for the passage and safe return of the Probe.

2. PROBE DESIGN

This section describes the Probe design and discusses some of the system components. The Probe was designed with the requirements and constraints as listed below.

2.1 Requirements and Constraints

Time: 20 hours drilling, 4-6 hours working time due to refreezing.
Bandwidth: at least 1Mbit/s for adequate real time feedback.
Size: 12 cm (5 inch) outer diameter.

Temp: 0 Celsius
 Schedule: 9 months, including testing.
 Redundancy: 2 complete Probe/reel systems.
 Sensors: Down and side looking cameras, with light sources.
 Data Storage: Digital Video
 Live Real-Time: In-situ video display.
 Reel: Single tether system

The above requirements and constraints dictated design decisions implemented to produce a highly functional, reliable, robust probe system.

The project team used off-the-shelf parts where possible in order to reduce cost, schedule, engineering development, and workforce. Figure 1 shows a sketch of the stainless

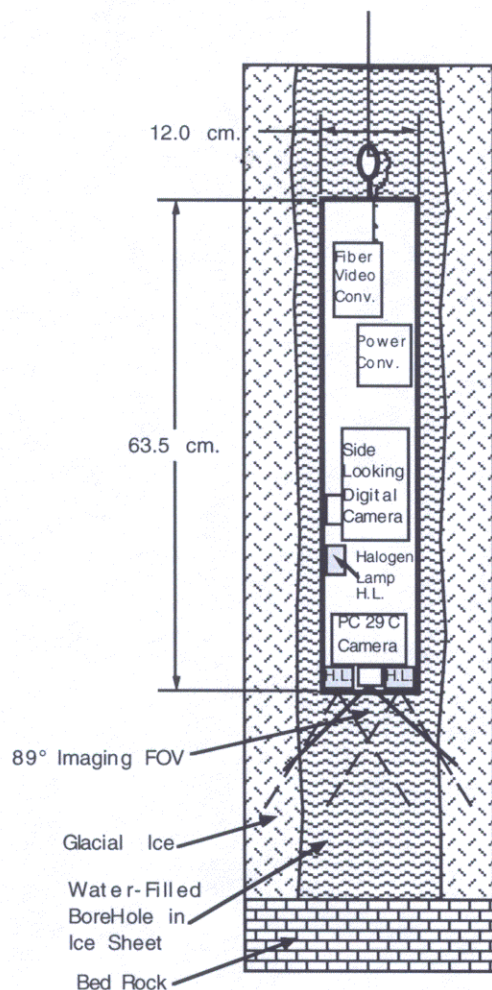


Figure 1 — Schematic of Ice Borehole Camera Probe deployed in ice well

steel Probe housing and the internal components, including the camera systems.

2.2 Probe hull. This portion of the Probe contains the cameras and associated electronics. Two CCD cameras are used. A high-quality digital camera (side looking) and a high-resolution video camera (down looking) acquire the

images. We use halogen bulbs to provide illumination, with one bulb for the side looking camera and two bulbs for the down-looking camera. NTSC Video-to-Analog fiber optic converters send images through the tether in real time to the surface Ground Station. For power, high voltage DC is sent down the tether cable and a 300V DC to 12 VDC converter provides clean power for the cameras and data transmission functions. The probe housing is used to conduct and dissipate heat from the electronics and power conversion units.

2.3 Deployment System. Figure 2 shows the deployment system that lowers the probe through the ice borehole. The spool is about 0.9 m in diameter, holding 1500 m of tether.

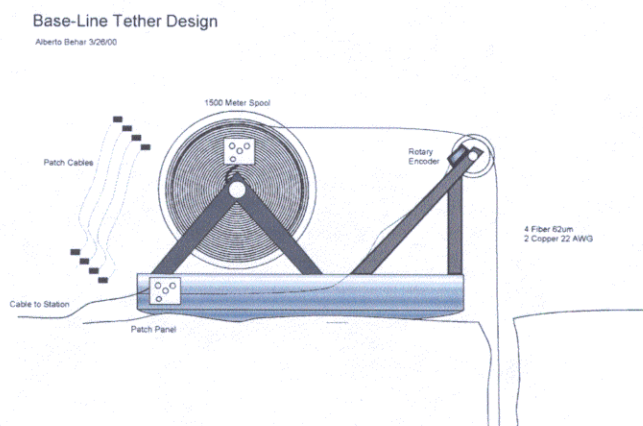


Figure 2 - Reel System

The tether is a reliable single cable system that provides data, power, structure, waterproofing and support (strength) members. The data are transferred along four optical fiber lines and power is transmitted along two 18 AWG wires. The entire unit, cable, spool, motors and sled, weigh approximately 400 lbs. The main spool is rotated with a three-phase AC motor giving a payout rate of about 1 m/s.

2.4 Ground Station. The Ground Station is shown in Figure 3. It contains the video display, control computer and recording devices.

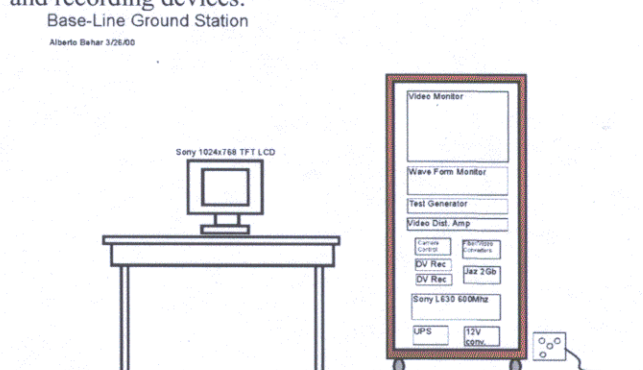


Figure 3 — Probe Ground Station

The display is a high-resolution video monitor that displays either of the video feeds sent from the probe. Two digital tape recorders are used to store the images as they are received. A Sony L620 PC computer is used after images

are acquired to digitally manipulate the images and analyze their contents.

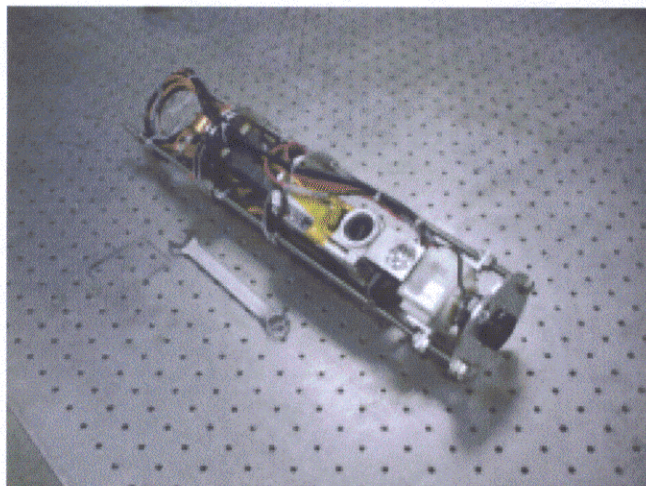


Figure 4 — Probe Instrumentation

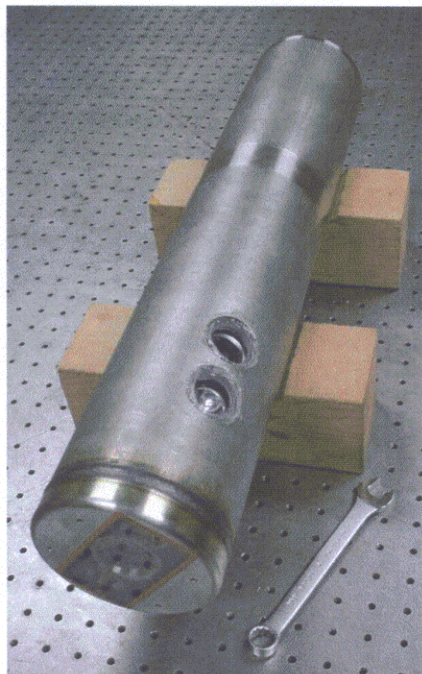


Figure 5 — Probe Pressure Hull, Showing Windows

2.5 Assembled Subsystems. Figures 4 and 5 are pictures of the actual units that were sent to Antarctica. Figure 4 shows the internal components held together by a frame containing two threaded rods that hold a series of plates. The plates support the cameras, lights and other components of the system. The pressure hull is shown in Figure 5 and contains the two quartz windows on the side (one for the camera and one for the halogen bulb). Also shown is the bottom quartz window for the two down looking lights and camera. Figure 6 is a diagram detailing the components and interconnections of the separate systems.

3. PROBE DEPLOYMENT

Although borehole picture systems have been applied successfully to problems in well-drilling, mineral exploration, and relatively thin valley glaciers (2) they have not been used previously in the study of ice sheets.

3.1 Test Deployment. The Probe is required to operate at high external pressure in Antarctica ice streams. In order to field test this requirement an end-to-end system deployment was conducted in Crater Lake, Oregon in August, 2000.

Crater Lake was selected as a test site for the Probe because it is the coldest, deepest lake that is logistically close to southern California. The test covered the integrity of the Probe and its in-situ operations; the actual test involved the deploying the Probe into the deepest portion of Crater Lake and imaging that portion of the lake bottom (~570m). The Probe was lowered and raised from a stationary boat via the tether system described above. This operation required the use of the National Parks Service research vessel Neuston, and the Probe team received excellent support from the National Parks staff. Figure 7 shows one of the images gathered during one of the preliminary deployments at the lake's fumaroles. The bars leading in to the picture are half-meter long metal rods with flags to visualize distances in front of the probe.

3.2 Field Deployment. The final field deployment of the Probe is at Ice Stream C in Antarctica (1). Its location is roughly 500 km from the South Pole and the surface temperature during the study will range from about -23°C to about -15°C .

The Caltech Antarctica program will drill a number of boreholes across Ice Stream C as part of their study of basal processes. Our approach is to deploy the Probe into some of these boreholes and record images of:

- 1) ice sheet — bed interactions as the ice moves, through sliding and deforming;
- 2) lower ice sheet structure with emphasis on identification of layers of ice thought to be accreted on the bottom of the ice sheet in slower moving areas called sticky spots;
- 3) observations of air bubbles and mineralogical inclusions in the ice; and
- 4) observations of isochronal layers which are ice formed from snow which fell after major volcanic eruptions.

In addition to the Probe, several other instruments will be deployed including: thermistor strings, pressure transducers, conductivity probes, ice motion sensors, etc. We also plan to take ice cores and sub glacial till samples for use in laboratory work. A total of 16 boreholes are planned during the 2000-2001 program. Shown in Figures 8 and 9 are sites from previous field deployments; this year's will be similar.

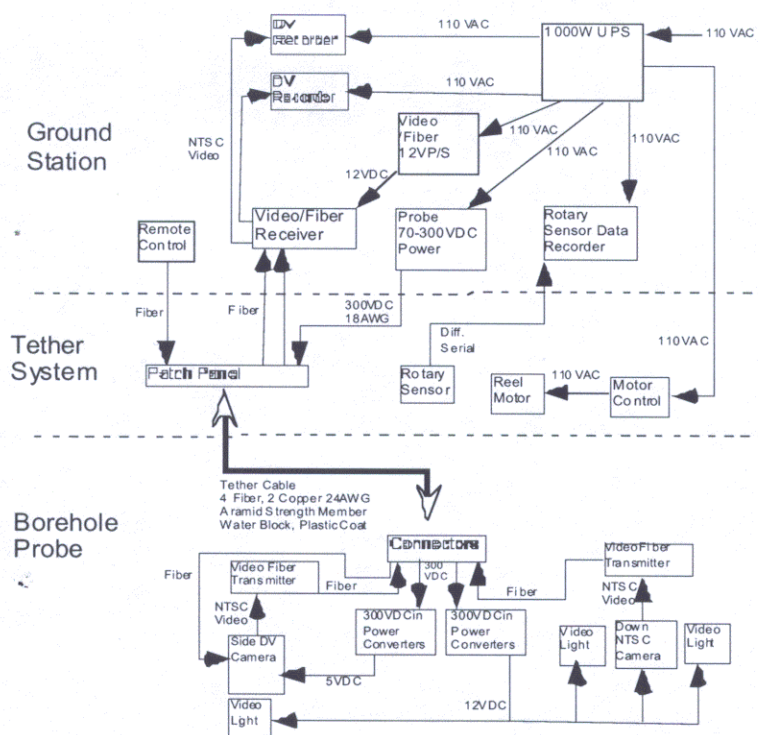


Figure 6 — Probe System Diagram

The Probe system diagram shown in Figure 6 gives an overview of the three main segments of the system being deployed in 2000-01. The power for the down-hole probe containing the cameras, light sources and the communication interfaces is derived from a 300 VDC power source located on the ice sheet surface above the borehole. The high voltage DC is impressed on the copper wire in the hybrid cable and, after resistance losses in the cable, the power is converted into 5 and 12 VDC busses. Video electrical signal data from the cameras are converted into optical streams and each is sent up separate optical fibers to the surface station. The downward looking camera has only a power-on, automatic operation mode. The side looking camera records internally up to 2 hours of digital video, as well as sending out a real-time, analog video stream. The side looking camera has focus control command function via an optical fiber command line from the surface; hence the scientist/operator can zoom and focus onto interesting objects seen in the real-time stream.

The tether system is a direct copy of reel systems utilized in past years by the Caltech group, with the only significant difference being the deployment cable which has optical fibers in addition to copper power lines and probe-supporting strength fibers. Each of the two identical reel systems contains about 1500 m of cable, adequate to reach to the deepest planned hole depths of about 1400 m.

The surface ground station provides power (110 VAC) for the computer equipment that records and displays image and engineering data, and issues commands to the probe.

Power is also generated at 300 VDC to go down the tether cable to the probe. The two cameras analog image data are recorded onto digital format recorders to preserve data quality, for many replays and the control station computer decodes the probe depth information from the cable reel rotations. All the data are time tagged to enable detailed correlations post-facto. To assist the operator to locate unique features, the real-time video display has sub-windows for depth and time. Command transmission for changing focus of the side-looking camera occurs from the ground station. The highest quality digital images, recorded on DV tape within the side-looking camera, are removed from the probe and camera housing after the probe is returned to the surface station. Time tagging provides a direct correlation between these taped images and the analog real-time recorded images.

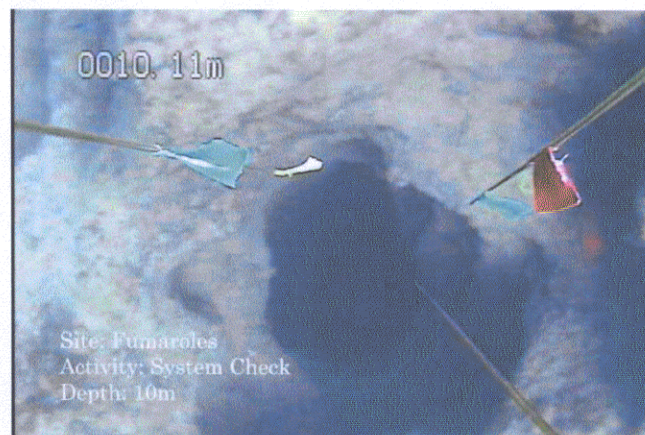


Figure 7 — Crater Lake Fumaroles

4. CONCLUSIONS

This research has the objective of gaining knowledge about the Antarctic ice sheet processes as well as enabling us to develop new technology to explore the icy/liquid environments of other planets. The future benefits of this project are to develop concepts and hardware for subglacial explorations such as of Lake Vostok and Europa, one of Jupiter's moons. At Europa, the ocean is thought to be somewhere between 10 and 40 kilometers below the icy surface. The challenge will be to descend through the ice, have a degree of mobility through the ice, acquire environmental data in the ice and explore the subglacial ocean. The Europa ocean may be as deep as 100 km and consequently at high pressure, about 1000 bars.

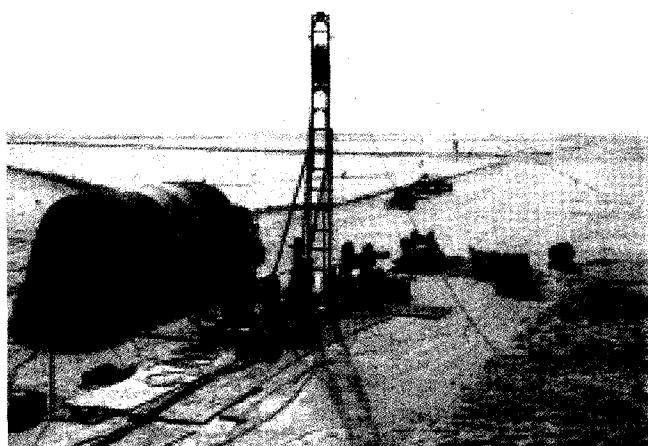


Figure 8 — Ice Borehole Probe Deployment Site

The basal regime of ice sheets and glaciers is of increasing interest. This interest stems from a new appreciation of the role of the rock-ice-water system processes of the subglacial in the dynamics of ice sheets (3), the response of (even quite large) ice masses to climate change, and the creation of habitat for a community of chemotrophic microbes thought to contribute to local biogeochemical weathering. Observational work (4) in the basal regime is challenging: the pressures are high, access is difficult, removal of ice samples is cumbersome because the warm ice is not competent, and the process of drilling into the ice alters the environment of interest. In the study for which the Ice Borehole Probe has been designed we address these issues through development of an in-situ deployment strategy which acquires a video record of the ice sheet adjacent to a hot-water drilled hole. The drilling process has not significantly affected this ice, either chemically or physically, and considerable information about it can be derived from other optical probes, e.g. Raman and fluorescent spectrometers, to be developed in future. Additionally, the probe will collect the first visual data set on the interaction of an ice sheet with its bed, in this case a mix of wet and frozen material. This unique inspection of a fundamental geological process is

of great interest. Clearly the system-level requirements on a subglacial probe are significant in all areas, including general robustness, high data rates, high pressure, lighting, tether management, and the like. This is the first time that all these matters have been considered in this sort of probe.

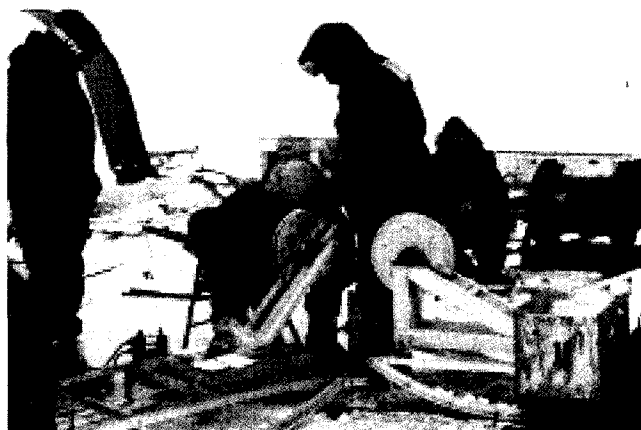


Figure 9 - Ice Borehole Probe Deployment

5. ACKNOWLEDGEMENTS

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7. BIOGRAPHIES

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